



Moore, T., Kesten, J., Lopez-Lopez, J. A., McAleenan, A., Ijaz, S., Richards, A., ... Audrey, S. (2018). The effects of changes to the built environment on the mental health and well-being of adults: Systematic review. *Health and Place*, 53, 237-257. <https://doi.org/10.1016/j.healthplace.2018.07.012>

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Link to published version (if available):
[10.1016/j.healthplace.2018.07.012](https://doi.org/10.1016/j.healthplace.2018.07.012)

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The effects of changes to the built environment on the mental health and well-being of adults: Systematic review

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ARTICLE INFO

Keywords:

Systematic review
Urban environment
Mental health
Well-being
Meta-analysis

ABSTRACT

There is increasing interest in the influence of place on health, and the need to distinguish between environmental and individual level factors. For environmental-level factors, current evidence tends to show associations through cross-sectional and uncontrolled longitudinal analyses rather than through more robust study designs that can provide stronger causal evidence. We restricted this systematic review to randomised (or cluster) randomised controlled trials and controlled before-and-after studies of changes to the built environment. Date of search was December 2016. We identified 14 studies. No evidence was found of an effect on mental health from ‘urban regeneration’ and ‘improving green infrastructure’ studies. Beneficial effects on quality-of-life outcomes from ‘improving green infrastructure’ were found in two studies. One ‘improving green infrastructure’ study reported an improvement in social isolation. Risk-of-bias assessment indicated robust data from only four studies. Overall, evidence for the impact of built environment interventions on mental health and quality-of-life is weak. Future research requires more robust study designs and interdisciplinary research involving public health, planning and urban design experts.

1. Background

Mental health and well-being are important public health issues. In 2010, mental health disorders accounted for 56.7% of 258 million global disability-adjusted life years (DALYs) (Whiteford et al., 2015). In the United Kingdom (UK) mental health problems are the greatest cause of disability (Mental Health Taskforce, 2016) and, although trends in self-reported personal well-being are improving, mental health continues to deteriorate (Office for National Statistics, 2017a). Promoting health and well-being is a World Health Organization (WHO) Sustainable Development Goal for 2030 (United Nations, 2015) and WHO’s Comprehensive Mental Health Action Plan calls for a “multi-sectorial approach” to protect mental health and prevent mental health problems (World Health Organization, 2013).

There is increasing interest in the influence of place on health, and the need to distinguish between contributions of “contextual” (environmental level) and “compositional” (individual level) factors to area level health differences has been argued (Macintyre et al., 2002).

The Scottish Government Health Inequalities Task Force also recognise the importance of environment on health and well-being (Scottish Government, 2008). Several systematic reviews highlight associations between environment and mental health and well-being (Won et al., 2016; Mair et al., 2008; Paczkowski and Galea, 2010; van den Berg et al., 2015; Lee and Maheswaran, 2011; Lavin et al., 2006; Gong et al., 2016; Croucher et al., 2007). However, evidence varies in quality and has tended to show associations through cross-sectional and uncontrolled longitudinal analyses rather than establishing causal effects through the use of randomized controlled trials (Barton et al., 2010; Bond et al., 2012; Ellaway et al., 2005; Guite et al., 2006; Horowitz et al., 2005; Stafford et al., 2007; White et al., 2013; Whitley and Prince, 2005; Wu et al., 2015). Cross-sectional analyses have the limitation that there is ambiguous temporal precedence (i.e. it is unclear which variable is the cause and which is the effect), and longitudinal studies without a control group do not allow the possibility to distinguish between effects of the intervention from effects due to events that occur concurrently with the intervention, naturally occurring changes

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<https://doi.org/10.1016/j.healthplace.2018.07.012>

Received 27 September 2017; Received in revised form 1 June 2018; Accepted 17 July 2018

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over time, or regression to the mean if the intervention group has been chosen due to extreme values (i.e. poor baseline mental health). Quasi-experimental studies, such as controlled before-after studies, if well-designed and performed, can reduce the risk of some of these barriers to interpretation. There is often no control for confounders such as healthier people choosing to live in neighbourhoods that support their mental health. Understanding these associations is impeded by: use of different measures of mental health, well-being and environmental domains; presence of mediators and moderators; and interactions between physical and mental health and well-being outcomes (Lachowycz and Jones, 2011).

Studies have indicated the following: neighbourhood aesthetic quality is positively associated with higher mental well-being (Bond et al., 2012); quality and accessibility of local environments in terms of availability of public transport, access to seating, attractiveness of the neighbourhood, and access to green space are key factors in improving use of the local neighbourhood by older adults (Stathi et al., 2012), and; risk of injury from traffic and disrepair of the built environment in low-income areas may adversely affect mental health (Lavin et al., 2006; Croucher et al., 2007; Ellaway et al., 2005; Horowitz et al., 2005; Stafford et al., 2007; Whitley and Prince, 2005).

Objective measures of urban environments (including neighbourhood quality, quantity of green space and land-use mix) have been associated with psychological distress (Gong et al., 2016). Similarly, objective measures of greenspace in living or home environments have been positively associated with perceived mental health (van den Berg et al., 2015; White et al., 2013) and negatively associated with depression and anxiety symptoms (Wu et al., 2015). However, Lee and Maheswaran (2011) concluded there is weak evidence for associations between mental health and well-being and urban green space, highlighting weak study designs in the literature.

Examining effects of modifications to the environment on mental health and well-being is complex and limited by methodological challenges associated with quasi-experimental evaluation. For instance, it is often challenging to define exposure to population level interventions and to identify an unexposed group (Egan et al., 2003; Ogilvie et al., 2010; Humphreys et al., 2016).

Most research and guidance to date has focused on relationships between the built environment and physical health rather than mental health and well-being (Egan et al., 2003; Bunn et al., 2003; Burns et al., 2014; Cerda et al., 2013; NICE, 2008; Tully Mark et al., 2013; World Health Organization, 2006). A systematic review of intervention studies examining effects of changes to the built environment on the health of children and young people found some evidence of potential benefits to physical activity but was unable to find any mental health and well-being outcomes in the literature (Audrey and Batista-Ferrer, 2015).

Responses to changes to the built environment to support health are likely to vary across the life-course (Villanueva et al., 2013). Worldwide, populations are ageing (World Health Organization, 2018) and in the UK specifically, the proportion of the population over 65 years is increasing (Office for National Statistics, 2017b) hence it is important to consider how changes to the built environment influence the mental health and well-being of adults and older adults. Furthermore, given exposure to green space is associated with fewer mental health disorders in older adults, it has been suggested planners should consider ways to encourage this group to use green space to support healthy ageing (Wu et al., 2015).

We found no systematic review evidence for intervention studies investigating effects of changes to the built environment on mental health and well-being in adults and older adults. This evidence is needed to inform recommendations to support policy decision making. The aim of this systematic review is to assess the evidence of changes to the built environment on mental health, well-being, quality of life, social inclusion and fear of crime in adults living in urban environments in high income countries.

2. Methods

A protocol with details of our planned research methods is registered with PROSPERO (Moore et al., 2015) and we reported the review according to PRISMA guidelines (Moher et al., 2009).

2.1. Search strategy

We searched using subject and text word terms for built environment (e.g. urban, built etc), intervention types (e.g. road safety, traffic calming, environment design, urban renewal etc) and terms describing mental health and well-being (e.g. wellness, quality of life, anxiety, stress etc). We focussed on adults and older adults as a recent review summarising effects of changes to the built environment on children and young people had been completed (Audrey and Batista-Ferrer, 2015). We restricted our search to studies published in English and excluded letters, editorials, and conference proceedings.

We searched 13 electronic bibliographic databases MEDLINE, PreMEDLINE, Embase and PsycINFO on OVID; Cochrane CENTRAL on The Cochrane Library; Core Collection on Web of Science; Database of Promoting Health Effectiveness Reviews (DOPHER); Trials Register of Promoting Health Interventions (TROPHI); Transport Research International Documentation (TRID) from US National Academies of Sciences, Engineering and Medicine; Health Evidence from McMaster University Canada; GreenFILE on EBSCO; Health Management Information Consortium (HMIC); GeoBASE on Elsevier and Planex. All databases were searched from inception to December 2016. We searched for grey literature and additional reports of research using Google, WHO trials registry, Clinical trials.gov, ISRCTN registry, OpenGrey, NHS Evidence, plus websites of 33 associations, charities, cities etc. (See [Supplementary material](#) for details of search terms used).

2.2. Inclusion criteria

We restricted study selection to randomized controlled trials (RCTs), cluster RCTs, controlled before-and-after studies, interrupted time series and regression discontinuity studies assessing the effects of any physical change to the built environment on adult or older adult mental health and well-being, quality of life, social inclusion or isolation, social capital, isolation or fear of crime.

We excluded studies in rural environments or low- or middle-income countries. It is expected that context specific factors are likely to influence the relationship between the built environment and mental health and well-being in these settings which would make drawing comparisons to high-income countries difficult. This approach is in line with previous research (Won et al., 2016; Lee and Maheswaran, 2011). Studies reporting introduction or upgrading of street lighting or closed circuit or surveillance cameras (CCTV) were excluded as these had recently been reviewed comprehensively (Lorenc, 2014). We excluded studies where changes were applied to environments not accessible to everyone or inside buildings (e.g. private grounds, schools, hospitals) as our interest was in the public realm. Studies where the main or sole intervention was either relocation from one area to another or improvement or refurbishment to the housing stock were also excluded.

2.3. Study selection, data extraction and analysis

We screened titles and abstracts and eligibility of full-text reports independently and in duplicate (TM, SI, JK, SA, SG). Data were extracted by one author and recorded on a predefined and piloted data extraction form and a second author checked extracted data (TM, JK, SI, AM, JLL). Extraction of numerical results and risk of bias assessments for each study were done by two reviewers independently (TM, SI, JK, AM, JLL). Any discrepancies in screening or data extraction were discussed until consensus was reached, with recourse to a third reviewer if required.

Study characteristics, (design, methods, description of intervention and control), participant characteristics (sample size, age, ethnicity, and socioeconomic status) and outcome (type, measure, time point, effects) were extracted. We extracted numerical results on four outcome domains: mental health and well-being, quality of life, social isolation and inclusion, and fear of crime. We were primarily interested in examining change from baseline to follow-up in the intervention group compared to the group that received no intervention. We extracted comparison data where reported or computed it when enough information was provided. Due to the different measurement scales used across studies, we transformed results into a common metric using a standardised difference-in-differences (SDID) index where the standard deviations at baseline provided an estimate of the pooled variation across groups (Rubio-Aparicio et al., 2017). Where several studies provided our comparison of interest for the same outcome using a validated measurement instrument, we displayed the effect estimates in a forest plot. Furthermore, we combined outcomes using fixed-effect meta-analysis if they were considered comparable in terms of study design (randomized vs observational), summary indices (means vs proportions) and adjustments (adjusted vs unadjusted estimate).

2.4. Risk of bias assessment

We used the revised Cochrane risk-of-bias tool for randomized trials (RoB 2.0) and risk of bias in non-randomized studies of interventions (ROBINS-I) tool to assess the risk of bias in extracted results (RoB 2.0 Tool, 2016; ROBINS-I Tool, 2016). ROBINS-I assesses risk of bias by considering the non-randomized study as an attempt to emulate a hypothetical RCT, designed without features putting it at risk of bias, for the same intervention, conducted on the same participant group – the target trial (Sterne et al., 2016; Higgins et al., 2011). The outcome of interest was the effect of assignment to intervention on mental health.

3. Results

3.1. Study selection

Our search retrieved 7476 records from which we identified 58 reports of 14 studies (see Fig. 1). We designated a name for each study and compiled a list of the principal paper and additional papers (Table 1 and additional Supplementary material). There was considerable heterogeneity in the type of intervention (See Table 1 and Fig. 2).

3.2. Summary of included studies

Eight studies were from the UK, (Ward Thompson et al., 2014, 2013; Phillips et al., 2014a; Huxley and Rogers, 2004; Stansfeld et al., 2009; Curl et al., 2015; Egan et al., 2016; Ogilvie et al., 2016) three from the USA, (Kondo et al., 2015; Branas et al., 2011; Shandas, 2015) and one each from Spain, (Mehdipanah et al., 2014) the Netherlands (Jongeneel-Grimen et al., 2016) and Norway (Skjoeveland, 2001). We categorised the studies based on the focus of the intervention or programme of interventions (Fig. 2) as ‘transport infrastructure modifications’ which included measures to improve walking and cycling, ‘improving green infrastructure’, and, ‘urban regeneration’ defined as community interventions with changes to the built environment or regenerating large areas of deprived areas in cities (e.g. housing demolition and improvement and new community buildings).

3.2.1. Transport infrastructure modifications

Two UK studies investigated the effects of a major change to road infrastructure on people aged 16 to over 65; ‘Noise reduction’ assessed the effects of a new road bypass in North Wales (Stansfeld et al., 2009) and the ‘Commuting and Health in Cambridge Study’ (CHCS) evaluated a purpose-built guided busway (segregated bus track) with an accompanying cycle and walking path linking towns and villages in

Cambridgeshire (Ogilvie et al., 2016). One controlled before-and-after study, ‘DIY streets’, involved redesigning streets to look more attractive and safer such as buildouts to slow down traffic, planters, benches and lights and included analysis of the effect on older adults (Curl et al., 2015).

3.2.2. Improving green infrastructure

Six controlled before-and-after studies described interventions in which more greenery was brought into neighbourhoods through trees, parks and lawns etc. Two interventions, ‘Green storm water Philadelphia’ (GSW Philadelphia) and ‘Green storm water Portland’ (GSW Portland) changed management of storm water runoff using natural planting rather than concreted storm water drains (Kondo et al., 2015; Shandas, 2015). These studies did not describe participant age in detail. The ‘Woods in and around town (WIAT)’ intervention tried to improve perceptions of urban woodlands through local community projects and physical changes (Ward Thompson et al., 2013). Three interventions (‘Greening Vacant Lots’, ‘Street-parks’ and ‘DIY streets’) introduced new mini-parks or green areas in residential streets (Curl et al., 2015; Branas et al., 2011; Skjoeveland, 2001). Mean ages for these three studies was 36–40 years.

3.2.3. Urban regeneration

Six studies investigated multifaceted large-scale interventions aimed at increasing physical activity and mental well-being either through community interventions with changes to the built environment or regenerating large areas of deprived areas in cities. Five of were controlled before-and-after studies (‘Wythenshawe regeneration’, ‘GoWell’, ‘Neighbourhoods Law’, ‘District Approach’, ‘NDC’) and one was a cluster RCT (‘Well London’). They took place in: Manchester, (Huxley and Rogers, 2004) Glasgow (Egan et al., 2010) and London (Phillips et al., 2014a) in the UK; deprived areas in the UK; (Walthery et al., 2015) Barcelona in Spain, (Mehdipanah et al., 2014) and; deprived areas in the Netherlands (Jongeneel-Grimen et al., 2016).

Many focussed on housing renovation (refurbishment and development to both the inside and outside of homes) and rehabilitation of social housing stock, and it was difficult to identify descriptions of changes to the public realm. ‘GoWell’ included relocation of residents and rebuilding of neighbourhoods but few descriptions of changes to neighbourhoods other than refurbishment to people’s homes. Urban regeneration across these studies also included social, economic and community based interventions for example: community engagement programmes, educational programmes, changes to tenancy agreements, public transport, and introduction of new facilities for people out of work or living on benefits and changes to the law (see Table 1).

3.3. Data collection tools and primary outcome

Data collection methods varied and included: routine data collection from household panel surveys (‘GSW Philadelphia’, ‘GSW Portland’, ‘Neighbourhoods Law’, ‘Greening Vacant Lots’); (Kondo et al., 2015; Branas et al., 2011; Shandas, 2015; Mehdiapanah et al., 2014) postal questionnaires (Well-London, Wythenshawe Regeneration) [49 50] and; face-to-face questionnaire completion by researchers visiting people in their homes (‘District Approach’, ‘DIY streets’, ‘Noise reduction’, ‘Street Parks’, ‘WIAT’) (Stansfeld et al., 2009; Curl et al., 2015; Ward Thompson et al., 2013; Jongeneel-Grimen et al., 2016; Skjoeveland, 2001).

Outcomes relied largely on self-report and involved a range of tools. Three studies assessed mental health from single survey questions asking if people felt anxious or depressed (Phillips et al., 2014a), or stressed (rated on a scale of 0–10) (Kondo et al., 2015; Branas et al., 2011). Other studies used validated multi-item scales: the mental component scales of the 12 item Short Form, quality of life scale (SF-12 MCS) (Egan et al., 2013a) and the 36-item SF(36) also called the Mental health inventory 5 (MHI)(5) (Jongeneel-Grimen et al., 2016); the 12-

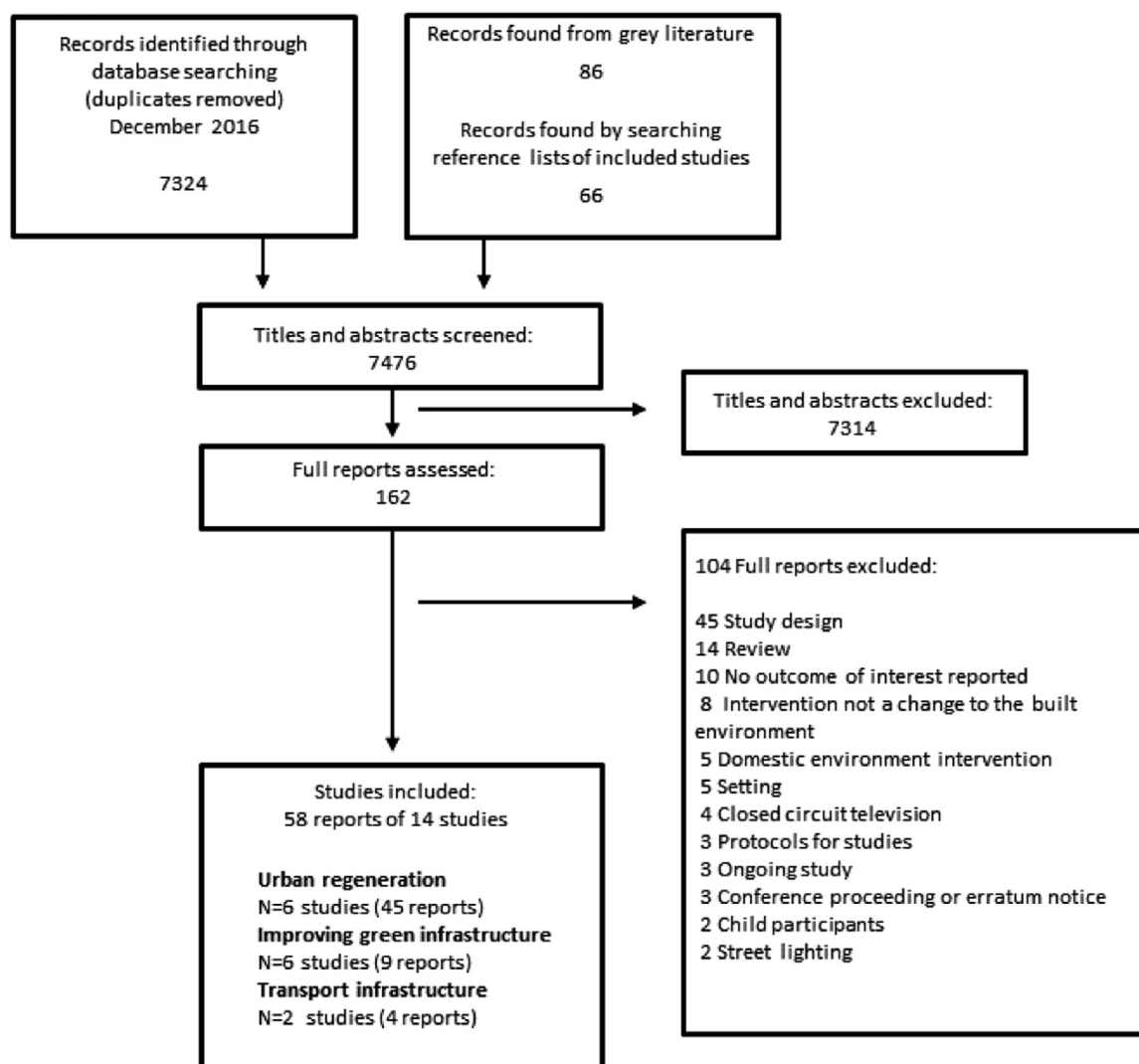


Fig. 1. Flow of studies through the review.

item General health questionnaire (GHQ) 12 (Phillips et al., 2014a; Huxley and Rogers, 2004; Mehdipanah et al., 2014); Health Satisfaction scale (Huxley et al., 2004); Warwick-Edinburgh Mental Well-being Scale (WEMBS), and; Revised Clinical Interview Schedule (CIS-R) and 28-item GHQ (Stansfeld et al., 2009).

3.4. Risk of bias

Risk-of-bias assessments, conducted on 13 studies for which outcome data were extracted, are summarised in Fig. 3. Considering risk of bias assessments on the mental health outcomes of 'Well London', 'GSW Philadelphia', Greening Vacant Lots, and 'Districts Approach', these data would appear to be robust. The cluster RCT, 'Well London', was rated 'low' risk of bias across all domains. Three of the controlled before-and-after studies ('GSW Philadelphia', 'Greening Vacant Lots', 'District Approach') scored well across most domains but without randomization the possibility of residual confounding persists and therefore were scored at 'moderate' risk of bias. Outcome data from the remaining nine controlled before-and-after studies should be read with caution as all were rated either 'serious' or 'critical' risk for 'bias due to confounding'. "This was related to having a single or few intervention and control sites ('Wythenshawe regeneration', 'Street Parks', 'GSW Portland', 'Noise reduction'); little adjustment for confounding ('Street

Parks', 'GSW Portland', 'WIAT', 'GoWell', 'NDC', 'Wythenshawe regeneration', 'DIY Streets'); or evidence of baseline imbalance ('Neighbourhoods Law', 'GoWell')."

All controlled before-and-after studies scored 'low' risk for bias for 'selection of participants' because selection of the groups of participants was not related to the intervention (or the effect of the intervention) and the outcome. Due to the nature of the interventions (changes in the built environment) we judged there was 'low' risk of intervention and control sites being 'misclassified' and 'low' risk due to 'departures from intended interventions'. However, 'Noise reduction' was rated 'serious' for this domain as the intervention of interest was the introduction of the bypass but both control and intervention sites were potentially affected by the bypass. The effect of bypass was assessed indirectly in this study. For the same reason, it was impossible to define a target trial for this study.

Five controlled before-and-after studies provided longitudinal data: each was rated as at 'serious' risk of bias for 'Missing data' as large numbers of people did not return questionnaires at follow up (NDC, 'Noise reduction', 'GoWell', 'Wythenshawe Regeneration' and GSW Portland). The remaining studies adopted a repeated cross-sectional design which does not suffer from attrition due to losses to follow-up unless a cluster/site drops out ('District Approach', 'Neighbourhoods Law', 'Greening Vacant Lots', 'GSW Philadelphia', 'WIAT', 'DIY streets',

Table 1
Characteristics of included studies.

Study name, Author, Year(s)	Location	Changes to the built environment: intervention description	Additional components of the intervention	Control	Participants	Sampling strategy	Data collection methods
Transport infrastructure							
'Noise Reduction' (Stansfeld et al., 2009)	Clwyd, North Wales	Road bypass built away from three towns and their main streets with 'high noise' from traffic.	None reported	Residents in nearby uncongested side streets with 'low noise' from traffic	Mean age (years, months) High noise group = 50 Low Noise group = 51.10 Gender (female %): High noise group = 55 Low noise group = 45; Ethnicity Not reported; Socioeconomic status % deprived High noise group = 67% Low noise group = 45%; Manual labour High noise group = 52% Low noise group = 58%; Crowded home High noise group = 0% Low noise group = 1%; Non-home ownership High noise group = 8% Low noise group = 3%; Unemployed High noise group = 63% Low noise group = 34%	Adults (16 years or over) living in households on the main streets facing traffic before the bypass was built, and a control population living in quieter adjacent side streets were eligible to participate	Questionnaire data collected in all streets simultaneously Clinical Interview Schedule-Revised (CIS-R) interviews conducted in participants' homes by researcher blinded to the General Health Questionnaire (GHQ) score of the participant which was conducted in the same month
'CHCS' Commuting and Health in Cambridge Study' (Ogilvie et al., 2016; Ogilvie, 2011)	Cambridgeshire, UK	Cambridgeshire Guided Busway built Purpose-built track with guided bus technology for buses with accompanying maintenance track for cycling, walking, horse riding and emergency vehicles that links Cambridge with local towns and villages Intervention area defined as either 600metre road network distance buffer around the stops along the urban sections of the Busway or larger areas encompassing the towns and villages along the rural sections of the route 'Intervention participants' lived within 30 km radius of Cambridge city centre and worked in areas of Cambridge served by the busway	None reported	Two areas, defined using home postcodes, of the city with no direct access to the busway and similar socioeconomic (SE) and spatial characteristics to urban parts of the 'intervention' area	Gender (female %) = 68.5 Age (years = %) < 30 = 16; 30-39 = 28.6 40-49 = 25.9; 50-59 = 21.3; Over 60 = 76 ;	Regular commuters aged 16 years or older Participants recruited through work places across Cambridge	Written questionnaire delivered by post Participants who engaged in the enhanced activity monitoring also received face-to-face visits
2 Improving green infrastructure							
'GSW Philadelphia' 'Green storm water Philadelphia' (Kondo et al., 2015)	Philadelphia, USA	Introduction of green storm water infrastructure Installations that allow infiltration or storage of storm water including tree trenches, rain gardens, pervious pavement instalments, bioswales, bump outs, a wetland and storm water basins	None reported	Control and intervention sites were randomly selected and matched in 4 sections of the city. Each intervention areas was matched with multiple control sites	Authors state control and intervention sites were not statistically different in age, household income, % of households earning less than the federal poverty standard (Not described in detail) Median % of the population with less than a high school-level education was lower in the intervention group than control	Philadelphia residents who completed the South-eastern Pennsylvania Household Health Survey for Public Health Management Corporation selected using random digital dialling	Survey repeated every 2 years with new cohort

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Table 1 (continued)

Study name, Author, Year(s)	Location	Changes to the built environment: intervention description	Additional components of the intervention	Control	Participants	Sampling strategy	Data collection methods
'GSW Portland' 'Green storm water Portland' (Shandas, 2015)	Portland, USA	Introduction of green storm water infrastructure Landscape changes to improve watershed function and sewer stormwater capacity by planting trees, repair and replacement of sewer pipe and addition of stormwater facilities in public right of way areas	Educational materials and workshops to engage community members in areas undergoing change	Two areas with no physical changes related to installation of stormwater facilities or educational materials about stormwater infrastructure	Socioeconomic status Bachelor's degree or higher (%) = 78 Annual income > \$50,000 (US Dollars %) = 65 Age (years, %) > 65 = 14 (Not described in detail)	Residents of Portland Oregon who completed the survey	All residents sent the survey by post at baseline (before intervention) Follow-up survey sent after 2 out of 8 neighbourhoods had received the intervention
'Greening vacant lots' (Branas et al., 2011)	Philadelphia, USA	Regreening of vacant building plots Four sections of the city turned into small gardens Rubbish and debris removed, ground prepared and trees and grass planted to create a "park-like" setting	None reported	Three building plots matched to each plot selected for intervention within four sections of the city	Median age per square mile (years) Intervention = 36.42 Control = 36.98 Median number of unemployed per square mile Intervention = 20.14 Control = 20.39 Median number of college educated residents per square mile Intervention = 71.96 Control = 87.57 (p < 0.001) Median annual household income per square mile Intervention = 18,362 Control = 20,233 (p < 0.001) Median number of black residents per square mile Intervention = 491 Control = 467 (p < 0.001) Median number of Hispanic people per square mile Intervention = 11.53 Control = 12.74 (P < 0.001) Median number of residents in poverty per square mile Intervention = 201.94 Control = 131.63 (p < 0.001)	Philadelphia residents who completed the survey South-eastern Pennsylvania Household Health Survey for Public Health Management Corporation selected using random digital dialling	Survey repeated every 2 years to new cohort
'DIY Streets' Paper 1 (Curl et al., 2015)	Multi-site, England, UK	Urban and landscape design improvements Improvements include unconventional road surfaces; raised platforms; gateway features to signal the entrance to a home zone; buildouts to slow down traffic; planters, benches and lights	Engagement with the DIY street community process.	Areas where no changes were made were selected near to and matched with intervention areas	Mean age (years) Intervention = 73.8 Control = 70.9 Gender (female %): Intervention = 63.2 Control = 68.7 Socioeconomic status Apart from Oxford all sites were selected from the top 40% of most deprived areas as defined by Indices of Multiple Deprivation in respective countries (Scotland, Wales, England) Ethnicity not white British (%) Intervention = 24.5 Control = 11.1	Older adults (65 years or older) residents Door-to-door leafleting, community meetings and information sessions	Survey administered by face-to-face interview

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Table 1 (continued)

Study name, Author, Year(s)	Location	Changes to the built environment: intervention description	Additional components of the intervention	Control	Participants	Sampling strategy	Data collection methods
'DIY streets' Paper 2 (Ward Thompson et al., 2014)	Multi-site, England, UK	See above	See above	Streets which did not receive an intervention that were matched to intervention streets	Mean age (years) Intervention = 75.92 Control = 74.11 Gender (female %): Intervention = 51 Control = 63 Socioeconomic status Ethnicity See DIY Street Paper 1 above	See above	Survey administered by face-to-face interview
'Street parks' (Skjoeveland, 2001)	Bergen, Norway	Street parks installed in urban residential streets Pavements removed, buildings demolished or unused land upgraded, asphalt replaced with boulder stone laid in patterns, trees and flowers planted, benches, tables and play equipment inserted. Car driving and parking prohibited	Authors describe "a new place" referring to a park that was built on previously unused land	Two areas: 1) already established street parks and 2) five streets like the intervention streets but without intervention	Adults mean age (years) = 35.6 Gender (female %) = 54 Living with a partner(%) = 47 Households with child aged 15 years or less (%) = 24 Employed and living in the area for a mean of 5.3 years (%) = 85	Residents living in intervention and control streets Up to three visits were made to retrieve questionnaires	Survey administered by face-to-face interview
'WIAT' Woods in and around town' (Ward Thompson et al., 2013)	Glasgow, UK	Investment in sustainable management of woodlands and improved recreation facilities in deprived areas Sites were chosen because they were in the top 15% of the Scottish Index for Multiple Deprivation. Under same local authority administration and were eligible to receive the WIAT intervention (high deprivation areas). Physical interventions included rubbish removed and vandalism repaired Improvements to footpaths, signage and entrance gateways Trees and vegetation pruned and cleared	Publicity about changes to the woods Group-based activities organised in the woods	Area eligible but did not receive the intervention	Age (years) Intervention = 47.04 Control = 42.6 Gender (female %) Intervention = 50 Control = 52 Socioeconomic status (%) Intervention AB = 2 C1 = 12 C2 = 12 D = 14 E = 61 Control AB = 1 C1 = 14 C2 = 12 D = 11 E = 61 Ethnicity (%) Intervention Scottish = 96 Other British = 1 Other white background = 2 Indian, Pakistani, Chinese or African = 0 Refused = 1 Control Scottish = 97 Other British = 1, Indian, Pakistani, Chinese or African = 1, Refused = 1	Residents living within 500m of the green spaces eligible for WIAT intervention Random quota sampling framework used to match survey sample to the national 2001 census for age, gender, and socioeconomic group for each area	Survey administered by face-to-face interview

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Table 1 (continued)

Study name, Author, Year(s)	Location	Changes to the built environment: Intervention description	Additional components of the intervention	Control	Participants	Sampling strategy	Data collection methods
3. Urban regeneration							
'Neighbourhood's Law' (Mehdipanah et al., 2014)	Llei de Barris, Barcelona, Spain	Urban regeneration in four neighbourhoods Reform of public spaces, refurbishment of community centre and other buildings, creation of a pneumatic garbage collection system, construction of a youth centre, reconstruction of a park, urbanisation and reform of several streets, creation of a park, creation of a health centre	Media and TV adverts, employment courses directed at women and immigrants, adult literacy and numeracy courses	Neighbourhoods matched to and in same districts as intervention but no intervention received Intervention area: neighbourhoods that participated in intervention between 2004 and 2011	Majority age (years) 35–64, manual workers and employed Most deprived neighbourhoods	Adults (over 15 years) who completed the Barcelona Health Surveys	Survey administered by face-to-face interview Data were collected from the Barcelona Health Survey. The data collection was consistent methods over all the years for this study.
'Wythenshawe regeneration' (Huxley and Rogers, 2004)	Wythenshawe, Manchester, UK	Urban regeneration Up to 45 million pounds of investment through the Single Regeneration Budget. No description of the physical changes to the built environment	Changes included tenancy from local authority to housing trust status Employment opportunities, education, training and, housing improvements at the street and house level	Regions matched with and neighbouring intervention region in South Manchester	Mean age (years) Intervention = 51 Control = 53; Gender (female%) = 48 Non-white (%) Intervention = 6 Control = 2; Single people (%) Intervention = 31 Control = 21; Unemployed (%) Intervention = 4.4 Control = 3.9; Paid employment (%) Intervention = 44 Control = 37; Not working because of ill health (%) Intervention = 8 Control = 14; Earning at or below minimum wage (%) Intervention = 27 Control = 22; Home owners (%) Intervention = 43 Control = 56; Income (pounds) Intervention = £614.27 Control = £804.81; General Health Questionnaire (GHQ)-12 Intervention = 2.6 Control = 2.3	Residents selected randomly to receive postal questionnaire	Residents sent survey by post
'Well London' (Phillips et al., 2014; Wall et al., 2009; Phillips et al., 2012)	London, UK	Multifaceted community based projects in deprived areas that included traditional health promotion, community engagement and changes to the built environment. Changes to the environment were curated through the "Healthy Spaces" project to develop existing and new sites for community gardens, allotments and play areas	Health walks, community arts projects and multifaceted themed project: "Be creative, Be well": supporting local cultural activities to foster social networks; "Buywell": to improve access to healthy food choices in local shops; "Changing minds": to raise awareness of mental health issues and understand its impact; "DIY Happiness": positive psychology activities to reduce impact of stress and increase psychological resources to cope with adversity; "Eatwell": to improve diet by raising awareness of its importance to physical and mental health	Randomly allocated areas given no additional intervention Most deprived Lower Super Output Areas (LSOAs) within 20 London boroughs accepted invitation to take part in project Two of the four most deprived LSOAs in each Borough identified conditional on the selected LSOAs not bordering each other One of the two was randomly allocated to the intervention group and the other to its matched control	Mean age (years) Intervention = 38.4 Control = 38.0 Gender (female %) Intervention = 52.7 Control = 57.5; Level of education (%) None Intervention = 8.8 Control = 11.8; Educated to Age 16 Intervention = 32.2 Control = 32.9; Education to Age 18 Intervention = 29 Control = 28; Degree Intervention = 29 Control = 27; Full employment Intervention = 43 Control = 42.8 Mental health 'Feeling anxious or depressed' (%) Intervention = 18.7 Control = 17.8	People living in the most deprived areas of London All adults (16 years or older) from households selected at random from home addresses for each of the LSOAs	Survey administered by face-to-face interview

(continued on next page)

Table 1 (continued)

Study name, Author, Year(s)	Location	Changes to the built environment: intervention description	Additional components of the intervention	Control	Participants	Sampling strategy	Data collection methods
'GoWell' (Egan et al., 2016; Bond et al., 2013)	Glasgow, UK	Urban renewal and regeneration in disadvantaged neighbourhoods Regeneration involving Glasgow housing association (GHA). £1.4 billion housing-led urban renewal programme over 10 years in 14 disadvantaged neighbourhoods. Programme included: housing demolition and improvement, new homes built, transformational regeneration, relocation of residents, new improved amenities, and services and community interventions Playgrounds described within 'Social programmes' (See Additional components). No further details of built environment changes described.	'Social programmes' addressing social needs, debt management, employment support, antisocial behaviour, vulnerable residents support	No official control group. But three investment levels were cited Low, Medium and High economic investment. 'Controlled experiment': people who were relocated from a neighbourhood undergoing regeneration were compared to people who remained (Bond et al., 2013) Pragmatic control group of participants who in 2008 had not experienced demolition or housing improvement due to unexpected delays (Bond et al., 2013)	Gender (female, %) Lower Investment = 67 Medium Investment = 61 Higher Investment = 56 Age (years, %) 16-39 Lower Investment = 21 Medium Investment = 32 Higher Investment = 26 39-64 years Lower Investment = 54 Medium Investment = 48 Higher Investment = 39 > 64 years Lower Investment = 26 Medium Investment = 32 Higher Investment = 35 Qualifications (%) Yes Lower Investment = 15 Medium Investment = 18 Higher Investment = 19 None Lower Investment = 86 Medium Investment = 81.8 Higher Investment = 81.3 Education (%) Yes Lower Investment = 14.6 Medium Investment = 18.2; Higher Investment = 18.7; Rented accommodation (%) Lower Investment = 72.1 Medium Investment = 71.4 Higher Investment = 81.4	One adult per household, sampled randomly from addresses in each study area	Survey administered by face-to-face interview Cross sectional survey data repeated over time and nested longitudinal sample identified through retrospective matching

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Table 1 (continued)

Study name, Author, Year(s)	Location	Changes to the built environment: intervention description	Additional components of the intervention	Control	Participants	Sampling strategy	Data collection methods
'NDC' 'New Deal for Communities' (Walthery et al., 2015; Beatty et al., 2008; Lawless et al., 2010)	Multi-site, UK	Urban renewal and regeneration £50 million spent on each of 39 most deprived areas of England, between 1998 and 2011. 11% spent on health.	Community, crime, child support, education, worklessness, and health initiatives	Areas with similar levels of deprivation as intervention areas and did not border each other No intervention received	Gender (female %) = 59.7; Mean age (years) = 46; Cohabiting (%) = 30.6; Non-White (%) = 23.3; Jobless household (%) = 43.1; Rent accommodation (%) = 58.8; NVQ 4 or 5 (%) = 13.4; In good self-reported health (%) = 40.4; Mean MHIS Score (%) = 71.4	Addresses within which households and one respondent age 16 or over selected at random completing national household panel survey	Survey administered by face-to-face interview
		Modernisation of social housing, new homes built, 'cleaning up' public spaces and remodel residential environments Improvements to property exteriors, gardens and alleyways and energy efficiency Traffic calming schemes introduced				People who provided data on at least two occasions	
'Districts Approach' (Jongeneel-Grimen et al., 2016; Droomers et al., 2014)	Multi-site, Netherlands	Urban regeneration funding 5 billion Euros for 40 target districts in The Netherlands in five policy areas: unemployment, educational level, housing conditions, safety and social cohesion Improvements to footpaths, cycle paths, parks, gardens and green areas. Also Housing improvement, new homes built and, removal of rubbish	Social interventions aimed at employment and income, debt management, tax reduction, preventing school drop outs and to improve social cohesion/ support and social capital, social safety including reducing burglary, vandalism graffiti and increasing traffic safety	Three districts (two matched with propensity scores, and one matched with the rest of the Netherlands)	Age (years) = 46.1 Gender (female %) = 52.8 Partner/married with children (%) = 35.5	Most 40 deprived districts in the Netherlands	Survey administered by face-to-face interview
					Partner/married without children (%) = 24.6 Single without children (%) = 27.0 Single with children (%) = 9.5 Other (%) = 3.4 Education (%) Primary = 20.8 Lower Secondary = 26.0 Upper secondary = 30.2 Tertiary = 23.0	Repeated cross-sectional data from the Dutch Health Interview Survey	

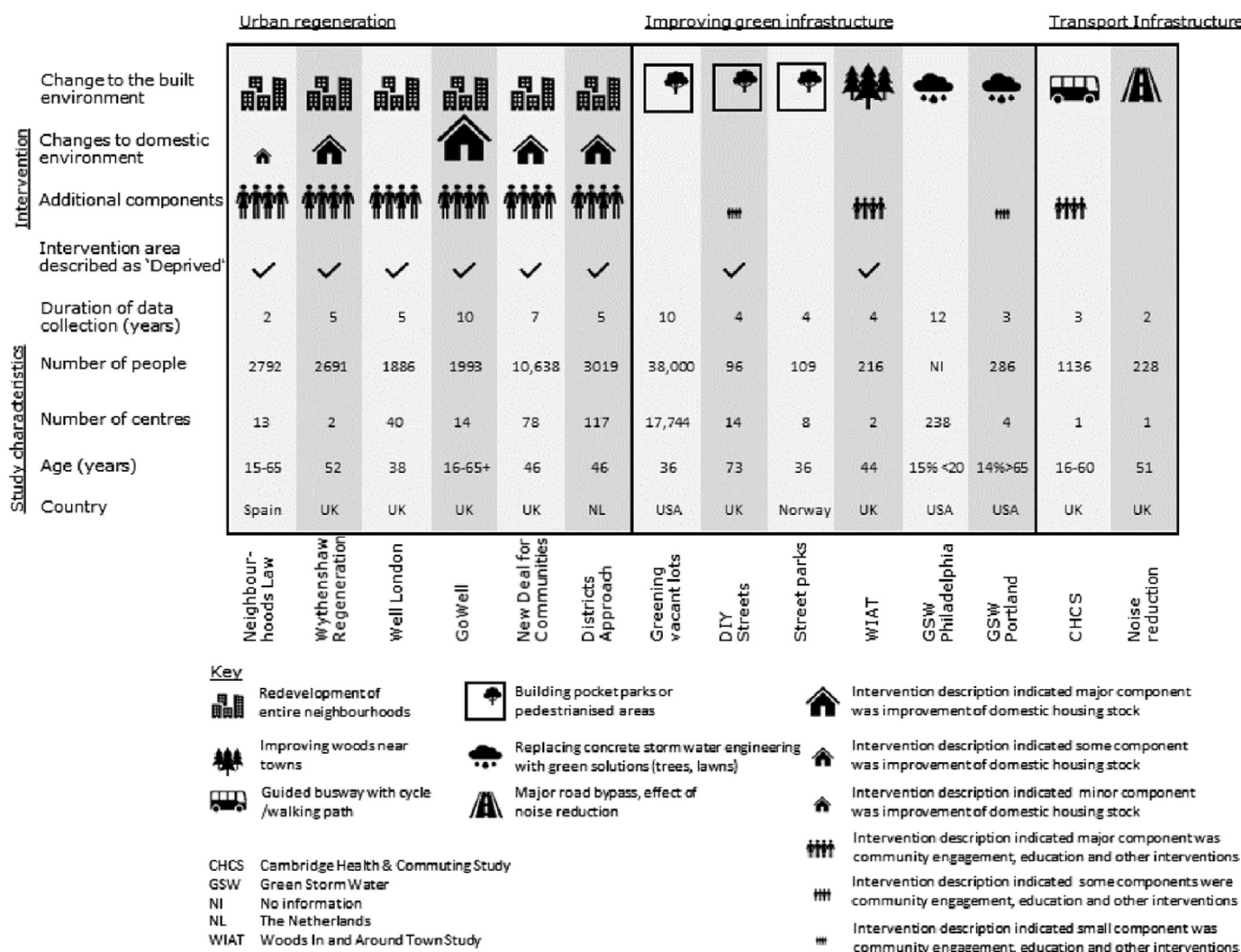


Fig. 2. Included studies showing variation of intervention and setting, and size.

'Street Parks'). Eight controlled before-and-after studies (NDC, 'GoWell', 'Wythenshawe Regeneration', Street Parks, WIAT, DIY Streets and 'GSW' Portland, 'Noise reduction') were rated 'serious' for 'Bias in outcome measurement' because participants reported subjective outcomes, were not blinded to intervention status and were probably aware of the hypothesis being tested. The remaining studies used

routinely collected data so, although participants were not blinded, it was judged they would have been unaware of the hypothesis being tested (Eldridge et al., 2016).

Nine studies were rated 'moderate' risk of bias for 'selection of the reported result' because there was no protocol or pre-specified analysis plan ('District Approach', 'Greening Vacant Lots', GSW Philadelphia', GSW Portland', 'Neighbourhoods Law', 'Noise reduction', 'Street Parks', 'Wythenshawe Regeneration' and 'WIAT'). 'DIY Streets' reported very little aggregate data and we wrote to authors for additional information, and was rated at 'serious' risk of bias (Ward Thompson et al., 2014). 'NDC' and 'GoWell' were both rated 'low' risk of bias as they had protocols and reported outcomes in full (Walthery et al., 2015; Egan et al., 2013).

3.5. Mental health and well-being outcomes

3.5.1. Urban regeneration

Fig. 4 presents a forest plot of effect estimates reported or computed from these six studies. Where possible, we present subtotals across

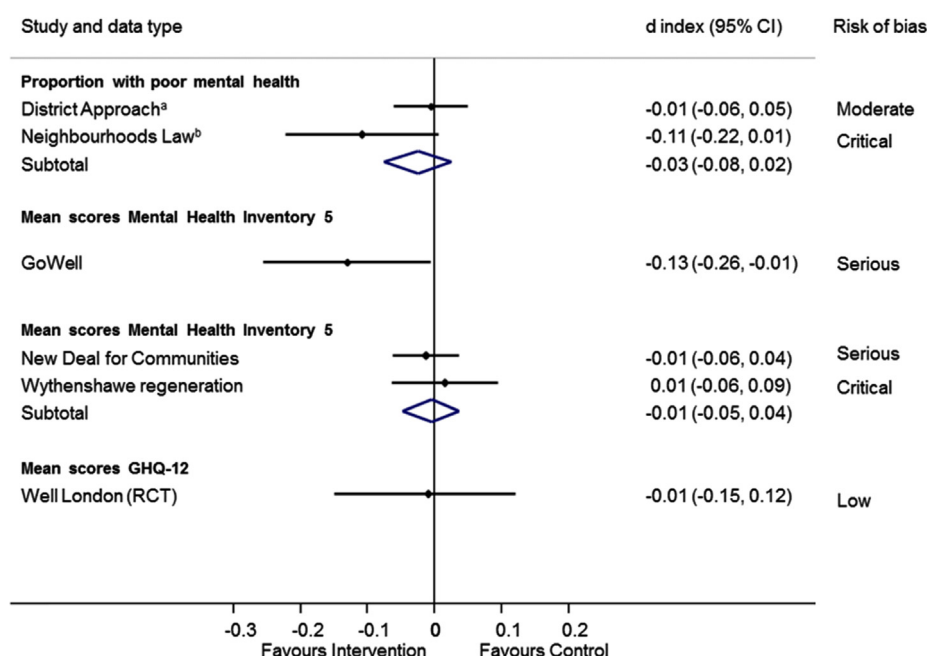
studies, although we remark that as such averages are based on two studies each no strong conclusions should be drawn from them. There was no strong evidence of an effect of urban regeneration interventions on mental health outcomes. 'Neighbourhoods Law' and 'District Approach' dichotomised their mental health scales grading people as having good or poor mental health. The proportion of participants with poor mental health in 'Neighbourhoods Law' was similar in the intervention group from baseline (0.180) to follow up (0.176), whereas it increased in the control group (0.138 at baseline to 0.173 at follow up). The proportion of people classified as having a mental disorder living in intervened districts of the 'Neighbourhoods Law' study was reduced at five years, with weak evidence suggesting a small beneficial effect for the intervention SDID = 0.11 (95% CI = 0.22 to 0.01), (Mehdipanah et al., 2014) but this study is at 'critical' risk of bias. When pooled with data from the 'District Approach' (3 years) (Jongeneel-Grimen et al., 2016) the overall effect was reduced to SDID = 0.03 (95% CI = 0.08 to 0.02). Pooled data from 'NDC' and 'Wythenshawe Regeneration' showed no effect on symptoms of mental health SDID = 0.01 (95% CI = 0.05 to 0.04). (Huxley and Rogers, 2004; Beatty et al., 2009a) In the one study where the majority of the intervention was focused on changes to the private, or home environment ('GoWell'), weak evidence of a small beneficial effect of the intervention was identified (SDID = 0.13, 95% CI = 0.26 to -0.01). Egan et al. (2013) Results from the 'Well London' RCT, suggested no differences in mental health between intervened and non-intervened areas (SDID = 0.01, 95% CI = 0.15 to

Intervention type Study name	Data collection method	1. Bias due to confounding	2. Bias in selection of participants	3. Bias in classification of interventions	4. Bias due to departures from intended intervention	5. Bias due to missing data	6. Bias in measurement outcomes	7. Bias in selection of the reported result	Overall risk of bias
Urban regeneration									
District Approach	Cs	MODERATE	LOW	LOW	LOW	LOW	LOW	MODERATE	MODERATE
Neighbourhoods Law	Cs	CRITICAL	LOW	LOW	LOW	LOW	LOW	MODERATE	CRITICAL
NDC	L	SERIOUS	LOW	LOW	LOW	SERIOUS	SERIOUS	LOW	SERIOUS
GoWell	L	SERIOUS	LOW	LOW	LOW	SERIOUS	SERIOUS	LOW	SERIOUS
Wythenshawe Reg	L	CRITICAL	LOW	LOW	LOW	SERIOUS	SERIOUS	MODERATE	CRITICAL
Improving green infrastructure									
Greening Vacant Lots	Cs	MODERATE	LOW	LOW	LOW	LOW	LOW	MODERATE	MODERATE
GSW Philadelphia	Cs	MODERATE	LOW	LOW	LOW	LOW	LOW	MODERATE	MODERATE
Street Parks	Cs	CRITICAL	LOW	LOW	LOW	LOW	SERIOUS	MODERATE	CRITICAL
WIAT	Cs	CRITICAL	LOW	LOW	LOW	LOW	SERIOUS	MODERATE	CRITICAL
DIY Streets	CS	SERIOUS	LOW	LOW	LOW	LOW	SERIOUS	SERIOUS	SERIOUS
GSW Portland	L	CRITICAL	LOW	LOW	LOW	SERIOUS	SERIOUS	MODERATE	CRITICAL
Improving road infrastructure									
Noise reduction	L	SERIOUS	LOW	SERIOUS	LOW	SERIOUS	SERIOUS	MODERATE	CRITICAL
Intervention type Study name	Participants, baseline and follow-up	1. Bias arising from the randomization process	2. Bias arising from timing of id & recruitment of participants relative to randomization	3. Bias due to deviations from intended intervention	4. Bias due to missing outcome data	5. Bias in measurement outcomes	6. Bias in selection of the reported result		Overall risk of bias
Urban regeneration									
Well-London RCT	Cs	LOW	LOW	LOW	LOW	LOW	LOW		LOW
<u>Key:</u> Cs =Cross sectional (two waves of cross sectional data); L = Longitudinal data; RCT =Randomized controlled trial; GSW=Green storm water; NDC=New deal for communities; Reg=Regeneration.									

Fig. 3. Assessment of risk of bias using ROBINS-I or Cochrane Risk-of-bias 2 tool.

0.12) (Phillips et al., 2012b). In addition ‘Well London’ reported results adjusted for age, gender, ethnicity, education, employment and appropriate baseline values, which yielded no differences on the Warwick-Edinburgh Mental Well-being Scale between intervened and non-

intervened areas (adjusted mean difference – 1.52, 95% CI – 3.93 to 0.88) (Phillips et al., 2012b). Also, single-item questionnaire evidence from the ‘Well London’ RCT reported no evidence of a reduction in people feeling anxious or depressed, SDID – 0.01 (95% CI – 0.06 to



^aPoor mental health defined as Cut off of > 3 on General health questionnaire 12 (GHQ-12)

^bPoor mental health defined as a score of ≤60 on mental health inventory 5 (MHI 5)

Fig. 4. Forest plot of mental health outcomes.

0.04) (Table 2) (Phillips et al., 2012b).

3.5.2. Improving green infrastructure

There was no effect of improving green infrastructure on mental health measured as stress in a single-item health question in ‘Greening vacant lots’ and ‘GSW Philadelphia’ studies (Table 2) (Kondo et al., 2015; Branas et al., 2011).

3.5.3. Transport infrastructure

The CHCS (Ogilvie et al., 2016) measured mental health but did not directly compare the intervened and non-intervened areas. We were therefore unable to record a treatment effect for intervention versus control or complete a risk of bias assessment. Intervention and control areas were defined by proximity to the new busway. For mental health outcomes they analysed those using the new route for active commuting (cycling/walking), compared to those who did not. They report improved mental health in the active commuting group, however this effect attenuated when controlled for baseline mental health (SDID 0.06, 95% CI – 0.05 to 0.18) (Ogilvie et al., 2016). ‘Noise reduction’ compared mental health of people who lived in streets with different levels of traffic noise following introduction of a bypass, but no differences were found (see Table 2) (Stansfeld et al., 2009).

3.6. Quality of life outcomes

3.6.1. Urban regeneration

There was little evidence of an effect of urban regeneration on quality of life outcomes. ‘Wythenshawe Regeneration’ reported evidence from a single item outcome scale and identified decreases in quality of life for both intervention and control groups, with an intervention group reporting a greater loss of quality of life, SDID = – 0.11 (– 0.21 to – 0.01) (Huxley et al., 2004). ‘NDC’ reported ‘life satisfaction’ at baseline was higher in comparator areas than intervened areas (Walthery et al., 2015; Beatty et al., 2009a). Following adjustment for demographic and socioeconomic factors they found no change overall but reported subgroup analysis suggesting people with lower

socioeconomic status (SES) experienced a decrease in life satisfaction compared to those in the control areas, while people with higher SES living in the intervened areas reported an improvement in quality of life compared to those in the control areas (Table 3) (Walthery et al., 2015). There was no effect of improving green infrastructure on mental health measured as stress in a single-item health question in ‘Greening vacant lots’ and ‘GSW Philadelphia’ studies (Table 2) (Kondo et al., 2015; Branas et al., 2011).

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3.7. Quality of life outcomes

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Table 2
Mental health outcomes.

Intervention type	Study name	Outcome measure	Timepoint	N Intervention/Control	Statistics as presented in the papers	Risk-of-bias Overall assessment	Direction of effect favours intervention control?	Re-analysis using summary data from studies Standardised difference in difference (95% Confidence intervals)
Improving green infrastructure	Green storm water Philadelphia (Kondo et al., 2015)	Single item question Stress ^a	2 years	N/A	Adjusted ^b difference in difference estimate for stress (SE) = − 0.01 (0.05) p = ns	Moderate	No effect	Not able to calculate
	Greening vacant lots (Branas et al., 2011)	Single item question Stress ^a	7 years	4436/13308	Adjusted ^c difference in difference estimate for Stress β = − 0.02 SE = 0.12 R ² = 0.68 p = ns	Moderate	No effect	Not able to calculate
	Neighbourhoods Law (Mehdipanah et al., 2014)	GHQ – 12 ^d	Baseline	274/504	^a Intervention Proportion poor MH = 0.180 SD = 0.38 Control Proportion poor MH = 0.138 SD = 0.345	Critical	Favours intervention	− 0.11 (95% CI − 0.22 to 0.01)
Urban regeneration		GHQ – 12	11 years	398/823	^a Intervention Proportion poor MH = 0.176 SD = 0.38 Control Proportion poor MH = 0.173 SD = 0.378			
	Wythenshawe regeneration (Huxley et al., 2004)	GHQ – 12	22 months	Total = 1344	MD 0.273 (95% CI − 0.134 to 0.481) p = 0.27	Critical	No effect	0.01 (95% CI − 0.06 to 0.09)
	Well London (Phillips et al., 2014a)	GHQ – 12	4 years	1867/1886	Adjusted MD − 0.01 (95% CI − 0.15 to 0.12) p = 0.4	Low	No effect	− 0.01 (95% CI − 0.15 to 0.12)
		GHQ – 12 ^d	4 years	1867/1886	Adjusted risk ratio 1.15 (0.82–1.61) p = 0.9	Low	No effect	Not applicable
		Single item Feeling anxious or depressed (%)	Baseline	2061/2046	Intervention mean = 17.8 (95% CI 13.6–22.0) Control mean = 18.7 (95% CI 13.6–23.8)	Low	No effect	− 0.01 (95% CI − 0.06 to 0.04)
		Single item question. Feeling anxious or depressed (%)	4 years	1867/1886	Intervention mean = 9.0 (95% CI 6.4–11.5) Control mean 8.4 (95% CI 6.4–10.4)	Low	No effect	− 0.01 (95% CI = − 0.06 to 0.04)
	Well London (Phillips et al., 2012b)	WEMBS	4 years	Intervention n = 1792–1886 Control n = 1825–1876	Adjusted MD = − 1.52 (− 3.93 to 0.88) p = 0.2 Intervention mean = 58.7 (95% CI 56.8–60.5) Control mean = 60.1 (95% CI 58.3–61.9)	Low	No effect	− 1.53 (95% CI − 3.93 to 0.88)
	District Approach (Jongeneel-Grimen et al., 2016)	MHI – 5 ^f	3 years	1445/7173	Adjusted difference of regression slope estimate ^g 0.00 (95% CI − 0.17 to 0.17)	Moderate	No effect	− 0.01 (95% CI − 0.06 to 0.05)
	GoWell (Egan et al., 2013)	SF12(MCS)	4 years	315/283	Intervention: Baseline mean = 47.97 Follow up mean = 49.22 b = 2.41 (SE = 1.17) Control: Baseline mean = 47.77 Follow up mean = 46.93 MD ^h 1.37 p = 0.122	Serious	Favours intervention	− 0.13 (95% CI − 0.26 to − 0.01)
	NDC (Beatty et al., 2009a)	MHI(5)	4 years	5499/458		Serious	No effect	− 0.01 (95%CI − 0.06 to 0.04)

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Table 2 (continued)

Intervention type	Study name	Outcome measure	Timepoint	N Intervention/Control	Statistics as presented in the papers	Risk-of-bias Overall assessment	Direction of effect favours intervention control?	Re-analysis using summary data from studies Standardised difference in difference (95% Confidence intervals)
Transport infrastructure modifications	Noise reduction (Stansfeld et al., 2009)	GHQ – 28	1 year	67/161 (high vs low noise site)	MD – 0.6 (95%CI – 2 to 0.8) p = 0.4 (fully adjusted)	Critical	No effect	– 0.6 (95% CI 2.0–0.8)
		CIS-R	1 year		Prevalence of common mental disorder at 1 year: high noise decreased by: 13.6% (95%CI 6–30)	Critical	No effect	– 0.11 (95% CI – 0.29 to 0.07)
		SF36(MCS)	1 year		MD – 1.9 (95%CI – 5.8 to 2.1) p = 0.35 (fully adjusted)	Critical	No effect	– 1.9 (95%CI 5.8–2.1)

CIS-R clinical interview schedule, revised. GHQ-12 General Health Questionnaire (12-item). GHQ-28 General Health Questionnaire (28-item). MD Difference in means.

SE Standard error. SF12(MCS) Short Form 12 Mental component scale. WEMBS Warwick Edinburgh mental health well-being scale.

^a Stress Outcome measure used: Southeastern Pennsylvania Household Health Survey, “Using a scale from 1 to 10, where 1 means ‘no stress’ and 10 means ‘an extreme amount of stress,’ how much stress would you say you have experienced during the past year?” Answers of 7 or more were defined as high stress.

^b Linear regression analysis, log transformed data to address heteroscedasticity in the crime counts and health. Measures were adjusted for age, site, income, education and sociodemographic variables.

^c Adjusted for demographics variables, lot area and clustering.

^d GHQ 12 Higher score = poorer mental health. GHQ 12 score dichotomised Score of 3 or more = poor mental health.

^e Proportions re-calculated from statistics in the paper.

^f MHIS score Dichotomised. A score of > 60 = fair or good mental health a score of less than 60 = fair or good mental health.

^g Multilevel multivariate logistic regression models taking into account clustering. Adjusting for age, gender, household composition, ethnicity, education and income.

^h Adjusted for demographics and baseline mental health.

overall but reported subgroup analysis suggesting people with lower socioeconomic status (SES) experienced a decrease in life satisfaction compared to those in the control areas, while people with higher SES living in the intervened areas reported an improvement in quality of life compared to those in the control areas (Table 3) (Walthery et al., 2015).

3.7.2. Improving green infrastructure

There is limited evidence for changes in quality of life from the ‘DIY streets’ multi-component intervention, which found that for intervened streets (those with improved traffic calming and landscaping), quality of life rose by on average by 3.82 points compared with a fall in the quality of life of people in the control streets of 7.25 points (Curl et al., 2015). This represents a SDID of – 0.54 (95% CI – 1.23 to 0.15) or a medium effect size (DIY Streets, personal communication) but the broad 95% confidence intervals include the null and with range of size of effect from very small increase to substantial decrease in quality of life (Table 3).

3.8. Social isolation/inclusion outcomes

3.8.1. Urban regeneration

‘NDC’ measured four aspects of social ties with the community, and found no effect on problems with social relations, extent to which people feel part of the community, extent that people are friendly in an area or the extent that people feel part of the local community (Beatty et al., 2009a).

3.8.2. Improving green infrastructure

Only ‘Street parks’ found any positive effect of improving green infrastructure on social isolation/inclusion outcomes. ‘Street parks’ increased ‘supportive acts of neighbouring’ (SDID – 0.68, 95% CI – 1.11 to – 0.25) as measured in one of the four domains from the Multidimensional Measure of Neighbouring scale but also increased ‘neighbour annoyance’ (SDID – 0.73, – 1.16 to – 0.30) (Skjoeveland, 2001). The authors also reported no effects on ‘social ties’ (SDID – 0.21, – 0.63 to 0.19) and ‘neighbourhood attachment’ (0.12, – 0.28 to 0.53) (Skjoeveland, 2001). Using a Likert scale, ‘GSW Portland’ showed no effect of improving green infrastructure on whether people felt a neighbourhood to be friendly or sociable (Table 3) (Shandas, 2015).

3.9. Fear of crime outcomes

3.9.1. Urban regeneration

Both ‘Well London’ and ‘NDC’ (Beatty et al., 2009a; Phillips et al., 2014b) assessed fear of crime in single survey questions. ‘Well London’ reported no difference between intervened and control areas on whether people felt safe either in the day or at night (Phillips et al., 2014b). ‘NDC’ found intervention areas reported a larger decrease in fear of crime between 2002 and 2006 (adjusted difference in means = – 0.67 p = 0.028) and people in the control groups reported feeling safer walking alone after dark compared with the intervention group (adjusted difference in means = – 0.14 p = 0.02) (Table 3) (Beatty et al., 2009a).

3.9.2. Improving green infrastructure

‘GSW Portland’ found no effect of the intervention compared to control on a single item, fear-of-crime, measure (Fig. 3) (Shandas, 2015). In the ‘WIAT’ study fewer people felt safe in woodland in the intervention compared to the control site, based on a single, fear-of-crime measure. However, the numbers of people who visited woodlands in the intervention community increased 25%, compared to the comparison site (Table 3) (Ward Thompson et al., 2013).

4. Discussion

We identified 14 diverse studies that met our criteria looking at

Table 3
Social inclusion isolation, quality of life, fear-of-crime, safety and well-being outcomes.

Outcome type	Intervention type	Study name	Outcome measure	Timepoint	N Intervention/ Control	Statistics as presented in the papers	Direction of effect favours intervention or Control	Re-analysis using summary data from studies Standardised difference in difference
Social inclusion/ isolation	Urban regeneration	NDC (Beatty et al., 2009a)	Extent feel part of local community	4 years	5499/458	Adjusted MD ^a = - 0.09 p = 0.159	No effect	Not able to calculate
		NDC (Beatty et al., 2009a)	Extent people in area are friendly	4 years	5499/458	Adjusted MD ^a = - 0.0 p = 0.989	No effect	Not able to calculate
	Improving green infrastructure	NDC (Beatty et al., 2009a)	Problems with social relations	4 years	55,499/458	Adjusted MD ^a = 0.0 p = 0.964	No effect	Not able to calculate
		GSW Portland (Shandas, 2015)	Friendly or social neighbourhood	2 years	90/42	MD = - 0.7	No effect	Not able to calculate
		Street parks (Skjoeveland, 2001)	Likert scale	2 years	38/37	Intervention mean = 2.47 SD = 0.90 p = ns	Favours intervention	- 0.68 (95% CI - 1.11 to - 0.25)
			MMN Supportive acts of neighbouring	2 years	38/37	Control 2 mean = 2.28 SD = 0.74	No effect	0.12 (95% CI - 0.28 to 0.53)
			MMN Neighbourhood attachment	2 years	38/37	Intervention mean = 3.17 SD = 0.68	No effect	- 0.21 (95% CI - 0.63 to 0.19)
			MMN Weak social ties	2 years	38/37	Control 2 mean = 3.17 SD = 0.49	Favours control	- 0.73 (95% CI - 1.16 to - 0.30)
			MMN Neighbour annoyance	2 years	38/37	Intervention mean = 4.45 SD = 1.24	No effect	Not able to calculate
				2 years	38/37	Control 2 mean = 4.36 SD = 0.96	Favours control	Not able to calculate
				2 years	38/37	Intervention mean = 1.75 SD = 0.66	No effect	Not able to calculate
				2 years	38/37	Control 2 mean = 1.72 SD = 0.61	Favours control	Not able to calculate
Fear of crime	Urban regeneration	NDC (Beatty et al., 2009a)	Fear of crime	4 years	5499/458	Adjusted MD ^a = - 0.67 p = 0.028	Favours control	Not able to calculate
		NDC (Beatty et al., 2009a)	Feel safe walking alone after dark	4 years	5499/458	Adjusted MD ^a = - 0.14 p = 0.020	Favours control	Not able to calculate
	Improving green infrastructure	Well-London (Phillips et al., 2012b)	Feel safe in the neighbourhood day	4 years	Intervention n = 1792 ^b to 1886	Adjusted MD ^b = 0.99 (95% CI 0.97–1.01) p = 0.3	No effect	Not able to calculate
				4 years	Control n = 1825–1876		No effect	Not able to calculate
		Well-London (Phillips et al., 2012b)	Feel safe in the neighbourhood night	4 years	Intervention n = 1792–1886 ^c	Adjusted MD ^c = 1.02 (95% CI 0.82–1.26) p = 0.9	No effect	Not able to calculate
				4 years	Control n = 1825–1876		No effect	Not able to calculate
		GSW Portland (Shandas, 2015)	Believe the neighbourhood to be safe with respect to crime	3 years	90/42	MD = 0.07 ns	No effect	Not able to calculate
		WIAT (Ward Thompson et al., 2013)	I feel safe in the woodlands (5-point Likert scale)	4 years	110/106	Intervention responses positive = 12% negative = 36% Control responses positive = 25% negative = 41% p < 0.05 ^d	Favours control	Not able to calculate
				4 years	5499/458	Adjusted MD = - 0.06 p = 192	No effect	Not able to calculate
		NDC (Beatty et al., 2009a)	Single question Likert scale quality of life	4 years	5499/458	MD = - 0.108 (- 0.209 to - 0.008) p = 0.034	No effect ^e	- 0.01 (95% CI - 0.05 to 0.04)
		Wythenshawe Regeneration (Huxley et al., 2004)	Health satisfaction	22 months	Total = 1344	Control = 7.25 Intervention = 3.82 (unpublished data) Cohen's effect size 0.54 (95% CI - 1.23 to 0.147)	Favours control	Not able to calculate
		DIY Streets (Ward Thompson et al., 2014)	Eq – 5d VAS	3 years	56/40		Favours control	Not able to calculate

Eq-5d VAS Euroqol-5D-Visual Analogue Scale.

MD Difference in means.

MMN Multidimensional measure of neighbourhood scale. The scale includes four domains 1) Supportive acts of neighbouring. As the score increases the supportiveness increases 2) Weak social ties. As score increases social ties improve. 3) Neighbourhood attachment. As the score increases neighbourhood attachment increases. 4) Neighbour annoyance. As the score increases the neighbourhood annoyance increases.

SD Standard deviation.

^a General linear models adjusted for key demographics and baseline variables.

^b Phillips et al provided a range of n for intervention and control because the analyses relied on complete case analyses, they did not provide a specific n for these difference in means.

^c Adjusted for age, gender, ethnicity, employment status, educational attainment and area summary health outcome measures.

^d Mann Whitney U test. Differences in variables within each site over time were analysed for significance.

^e Baseline imbalance (intervention group had lower health satisfaction than control) were taken into account in the calculation of standardised difference in difference.

interventions to the built environment and mental health and well-being of adults. Overall, we found a lack of evidence for an effect of built environment interventions on mental health and well-being outcomes. Small positive effects on fear of crime, social isolation/inclusion and quality of life outcomes were found in the ‘NDC’, ‘Street parks’ ‘DIY streets’ and ‘WIAT’ studies. However, apart from ‘NDC’, these studies received unfavourable assessments of risk of bias and their findings should therefore be interpreted with caution.

4.1. Heterogeneity

Interventions ranged from large-scale neighbourhood refurbishments to small ‘do-it-yourself’ parks in abandoned building sites. Furthermore, the description of the interventions was clear for some studies but problematic for others, especially when attempting to identify what changes had been made to the public realm in the large urban regeneration interventions. Study design also varied: we included one RCT and the rest of the studies were controlled before-and-after studies, some of which studied a longitudinal cohort of participants and others performed repeated cross-sectional surveys. The more robust studies included multiple intervention and control sites and studies set up prospectively before an intervention was implemented. Other studies were limited to opportunistic assessment of a single new development, and so were unable to adequately assess the impact of the intervention. Data collection methods also varied and included routine data collection from household panel surveys, postal questionnaires and face-to-face questionnaire completion by researchers visiting people in their homes.

4.2. Measuring outcomes

Outcomes for included studies depended largely on self-report and involved a range of tools. Some outcomes were measured using validated, multi-item scales and some involved single-item questions. Researchers use single-item questions to reduce time or the burden on participants, or where it is pragmatic to do so and, for example, using data from a national survey, with a single question on depression, enables large sample sizes. This variation also restricted opportunities for meta-analysis. However, there is evidence single-item, self-rated health questionnaires can correlate well with multi-item health questionnaires for mental health and other health related measures (Ahmad et al., 2014; DeSalvo et al., 2006). They are gaining traction as a means of measuring health (Bowling, 2005) and it would help future reviewers if there was some standardisation of these measures.

4.3. Risk of bias and limitations of the evidence

We used the RoB 2.0 for cluster RCTs and ROBINS-I tool to assess risk of bias of outcomes from the included studies (RoB 2.0 Tool, 2016; ROBINS-I Tool, 2016). This tool was developed for clinical studies, although an adaptation for controlled before-and-after studies and for public health interventions is currently in development. The ROBINS-I tool highlighted areas in which studies had been able to minimise bias, and ways in which the rating for risk of bias could be improved, some of which are discussed here.

Non-randomized, quasi-experimental study designs, such as controlled before-and-after studies can provide useful evidence if well designed. A key assumption for causal inference in controlled before-and-after studies is that the control group represents what would have occurred in the intervention group in the absence of the intervention. Therefore, the control group needs to be selected with care. However, defining exposure to changes to the environment can be difficult and problematic (Humphreys et al., 2016). An alternative may be to create a virtual control made out of weighted data from several areas, (de Vocht et al., 2017) individual computed distances (CHCS), individually calibrated exposures related to loci of activity or by observing actual

exposure e.g. through use of portable electronic devices, or big data (Humphreys et al., 2016). Many of the CBA studies we included in this review contained only a single intervention and control site. When this is the case it is difficult to attribute any observed differences to the intervention rather than other site-specific variables. In studies with multiple sites, adjusting for important confounders in the analysis of the outcome (including socioeconomic status, age and gender) also reduces risk of bias and four of our studies did this for the mental health outcome.

The four studies that followed a longitudinal cohort of people all scored ‘serious’ risk of this bias as there were considerable missing data from baseline to follow-up often running to over 50% of the population and thousands of participants (‘GoWell’, ‘GSW Portland’, ‘NDC’ and ‘Wythenshawe Regeneration’) (Huxley and Rogers, 2004; Kondo et al., 2015; Jongeneel-Grimen et al., 2016; Egan et al., 2010). None of the studies reported the difference in numbers of people followed-up between intervened and control areas.

Although mental health outcomes are subjective and self-reported, and it is impossible to blind people to whether a change in the built environment has occurred, it is possible to blind people to the comparison being made or the hypothesis being tested. Studies using routinely collected data were rated at lower risk of bias, as we judged participants would not know they were in a study. This highlights a trade-off between the benefits of using routine data collection, say from household panel surveys which might include single-item questions on anxiety or depression, with multi-item mental health questionnaires administered by research personnel. Single item scores are gaining credibility as a useful alternative when multiple item outcome measures are not feasible (Ahmad et al., 2014; DeSalvo et al., 2006; Bowling, 2005).

Eight of the included studies adopted a repeated cross-sectional design. People might have moved (either into or out of a study area) for the second wave of data collection for reasons associated with the intervention. However, several studies compared features of the participants at both waves of data collection and found them to be similar, or performed sensitivity analyses excluding new-migrants, and found no effect on the observed results. In addition, recent research has indicated this self-selection hypothesis did not hold true for physical activity (James et al., 2015). A previous systematic review of the risk of bias in natural experiments of changes to the built environment on physical activity used the fore-runner of ROBINS-I the ‘Cochrane Risk of Bias Assessment Tool: for Non-Randomized Studies’ of Interventions, (ACROBAT-NRSI). They identified similar research priorities to this review that could improve methodological limitations of research (Benton et al., 2016) including: “better matching of control sites and more nuanced use of graded exposure; use of multiple control sites and controlling for confounding domains” (p14).

One of the five actions the WHO listed to improve health for people living in cities was to “Promote urban planning for healthy behaviours and safety” (World Health Organization, 2010), perhaps a more directed action, would be to embed robust research into all major town planning decisions to build a body of evidence. We also noted a dearth of studies looking at more modest changes to cities such as provision of footpaths, foot bridges, public lavatories, benches, etc. In addition, there are other questions to be considered which relate to the intervention and the context and implementation of the intervention. These issues are best investigated through robust process evaluation. However, consideration should also be given to what counts as ‘robust enough’ evidence of effectiveness. Although we conclude that more robust studies are needed, we did find studies that reported small positive effects on fear of crime, social isolation/inclusion and quality of life outcomes. There also must be a call to evaluate, where there is evidence of promise, this may be a starting point for implementing stronger interventions with more robust evaluations in future.

We aimed also to review the impact of interventions on adults and older adults. However, in some studies the age of participants was not presented and given the limited evidence available a comparison of

effects by age subgroups was not possible.

4.4. Comparison to other literature

Existing systematic reviews on this topic included data from uncontrolled studies and consistently report an association between existing environment and mental health with poorer mental health in areas that are less green, perceived as having neighbourhood problems, or being unsafe (Won et al., 2016; van den Berg et al., 2015; Lee and Maheswaran, 2011; Lavin et al., 2006; Gong et al., 2016; Croucher et al., 2007; Thomson et al., 2006). Lorenc et al identified 14 controlled studies on street lighting and reported mixed evidence for a reduction in fear of crime; CCTV and multi-component interventions were not effective; and improvements to public areas showed an effect but they characterised the evidence as weak. They included one urban regeneration study and found no effect on fear of crime (Lorenc et al., 2013). The majority of these reviews also report that the evidence is weak, that causality can be implied rarely, and recognised the need for studies to investigate causal links using controlled data or more sophisticated study designs.

An important question arising from this review and previous research (Humphreys et al., 2016; Lawlor et al., 2003; Petticrew et al., 2005; Thomson, 2008) is why the evidence for the impact of interventions that are changes to the built environment is so poor, and what can be done to strengthen the evidence base? In synthesising the evidence, we have, necessarily, focused on bias relating to study design. And from that work, it appears that some study designs being used seem ill-suited to assess changes to the built environment. So the wider question is how do we promote the use of other types of analysis methods in this field? Natural experiments either with a suitable control or with good quality baseline and follow-up data can be used to assess changes to the built environment (de Vocht et al., 2017; Petticrew et al., 2005; Bernal et al., 2017; Bor et al., 2014). Interrupted time series can provide convincing evidence of effect if the following conditions are met. There are measurements at sufficient time points prior to the intervention so that the trend in the absence of intervention can be modelled. And there should be confidence that no other concurrent naturally occurring events could have influenced the outcome (Bernal et al., 2017). Regression discontinuity analyses can be designed to reduce the effects of confounding (if a small window around the cut-off on the allocation variable is used people on both sides of the cut-off can be considered to be similar) (Bor et al., 2014; O’Keeffe et al., 2014). However we did not find studies using either of these designs. And in using them, researchers are likely to continue to face considerable methodological difficulties (Humphreys et al., 2016; Lawlor et al., 2003; Petticrew et al., 2005; Ogilvie et al., 2006).

It is important to note that mental health and well-being were not the primary outcome of most of the included interventions. Further consideration of the causal processes triggered by changes to the environment which could affect these specific outcomes is needed (Thomson, 2008; Parry et al., 2004). A greater understanding of these processes may help to understand why we found limited effects and help enhance the effects of similar interventions in the future. Indeed, causal pathway analyses may help understand which groups are a) exposed to the intervention or not (Humphreys et al., 2016; Mehdiapanah et al., 2015) and b) whether certain groups are more susceptible to intervention effects (Parry et al., 2004; Mehdiapanah et al., 2015). Including qualitative research nested within quantitative evaluations can help us identify how people interact with a change to the built environment and might be useful in determining which populations of people to study (Thomson, 2008; Mehdiapanah et al., 2015). Furthermore, measurable changes in population level mental health and well-being outcomes may take a long time to emerge.

Internationally, governments have been looking to promote health and reduce health inequalities through neighbourhood renewal and regeneration initiatives (World Health Organization, 2006; Barton

et al., 2003; Mackenbach and Bakker, 2003). One of the most extensive urban regeneration projects ‘NDC’ reported that large scale area-based initiatives can lead to increased residential mobility (Beatty et al., 2009b) but increased mobility may indicate both positive and negative associations. While urban regeneration is associated with improved housing and/or provide better opportunities for employment, at the individual level, (Bailey and Livingston, 2007) mobility from deprived neighbourhoods may also result in weakened social bonds and cohesion (Laurence and Heath, 2008). In addition, residential mobility affects subgroups of the population to different extents, NDC found that residential mobility was greater in younger adults (16–34 years) and in areas with high levels of private rented sector housing (Beatty et al., 2009b). These complex relationships between urban regeneration and mobility may help to explain why it is difficult to determine changes in population level mental health in these studies. In this review eight of the fourteen studies used a cross sectional design with different people at follow-up, and all five longitudinal studies were rated at ‘serious’ risk of bias for missing data, highlighting both attrition and population turnover as key issues.

Interventions to modify the environment and address factors associated with mental health and well-being can result indirectly from government policy and directly through investment in local development and health initiatives. Policy makers and neighbourhood planners are urged to consider the ‘*nature, drivers and consequences of residential mobility in deprived neighbourhoods*’ and furthermore recommend a detailed knowledge of the local area when developing local initiatives (Beatty et al., 2009b).

To increase population levels of happiness, a feature of well-being, it is recommended planners implement designs that support opportunities for social interaction, feelings of safety in the environment and increase access to open green space (Barton et al., 2003; Pfeiffer and Cloutier, 2016). However, the public do not always agree with planner-anticipated benefits from changes to the environment (Ogilvie et al., 2010; Trayers et al., 2006; Mehdiapanah et al., 2013). For example, in response to proposed changes to the environment designed to increase access and connection between residential areas and city centres, public perceptions of fear of crime and antisocial behaviour increased (Trayers et al., 2006; Mehdiapanah et al., 2013).

4.5. Strengths and limitations of the review

We adopted rigorous systematic review methods and reported according PRISMA guidelines (Moher et al., 2009). We conducted a broad search of electronic bibliographic databases and grey literature. However, we restricted our search to publications written in English and this may have resulted in some studies being missed. This review focused on urban environments in high-income countries.

5. Conclusion

There is currently very little robust public health evidence from intervention studies that changes to the built environment can improve mental health, quality of life, social isolation or inclusion. Our review identified a relatively large number of studies and some of them were of reasonable quality, however they found a very small or no effect of built environment on mental health and wellbeing. This leads us to ask some serious questions: Can the effects of these interventions be measured using the methods at our disposal? Is measuring one ‘primary’ health outcome at one or two time-points too narrow? Perhaps research is needed to ask ‘why?’ these interventions appear to have little or no impact. Are the contextual backgrounds against which such outcomes are measured too nuanced and complex for us to take into account? Finding out ‘why?’ will likely require a different type of research and may need to go beyond the traditional comparative effectiveness research.

Acknowledgements

TM, SI, JS, JLL and AR's time was supported by the National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care West (CLAHRC West) at University Hospitals Bristol NHS Foundation Trust.

JK is partly funded by National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care West (CLAHRC West) at University Hospitals Bristol NHS Foundation Trust and NIHR Health Protection Research Unit in Evaluation of Interventions.

The work was undertaken with the support of The Centre for the Development and Evaluation of Complex Interventions for Public Health Improvement (DECIPHer), a UKCRC Public Health Research Centre of Excellence. Joint funding (MR/KO232331/1) from the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, the Welsh Government and the Wellcome Trust, under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged.

SG is partly funded by National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care West (CLAHRC West) at University Hospitals Bristol NHS Foundation Trust and University of the West of England, Bristol.

The views expressed are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health.

Author contributions

SA, SG, JS and TM designed the study with input from JK, JLL, and SI. SA is the principal investigator and TM is the lead reviewer. JK, SI, SG are secondary reviewers. SG, SA, JK, AM and TM screened titles and abstracts and full-text papers and extracted data. TM, AM, SI, JK and JS applied the ROBINS-I. TM, JK, SA and SG wrote the first draft of the manuscript. Alison Richards developed the search strategy and conducted the searches. JLL provided statistical analysis and extracted data. All authors have critically revised the manuscript and approved the final version.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at <https://doi.org/10.1016/j.healthplace.2018.07.012>.

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